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Rulison-1

USGS-474-16

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

Federal Center, Denver, Colorado 80225

Geology and Hydrology of the Project Rulison Exploratory Hole, Garfield County, Colorado

April 4, 1969

Open-file report

This report is preliminary and has not been edited for conformity with Geological Survey format and nomenclature.

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GEOLOGY AND HYDROLOGY OF THE PROJECT RULISON EXPLORATORY HOLE, GARFIELD COUNTY, COLORADO

by

Paul T. Voegeli, Sr.

ABSTRACT

Hydrologic tests on the Rulison exploratory hole indicated that little or no water occurs in the Ohio Creek Conglomerate and Mesaverde Group which are the stratigraphic units most likely to yield water to the hole. Six depth intervals, beginning at 6,129 feet and ending at 8,018 feet, were tested. Pressures recorded during the testing of the individual zones indicated little or no fluid entry while the test tool was open.

INTRODUCTION

Project Rulison, a Plowshare Project, is a cooperative effort of the Austral Oil Company, Inc., as operator, the CER Geonuclear Corporation, as technical consultant, the U.S. Atomic Energy Commission, and the Los Alamos Scientific Laboratory.

The purpose of the project is to determine the commercial feasibility of nuclear stimulation of natural-gas reservoirs. The experiment will include: 1) the detonation of a nuclear device in the Mesaverde Group, a natural gas-formation that is not commercially productive with present conventional methods of gas-field development, and 2) evaluation of the effect of the detonation on the gas-producing capability of the formation.

The exploratory hole (hole R-EX) was drilled to obtain data to be used in defining the characteristics of the gas reservoir and the geologic and hydrologic conditions at the site. This report describes the general geologic features and the hydrologic testing of the exploratory hole.

The experimental site is located in the Piceance Creek basin, SW¼ sec. 25, T. 7 S., R. 95 W., Garfield County, Colorado, in the Rulison gas field (fig. 1).

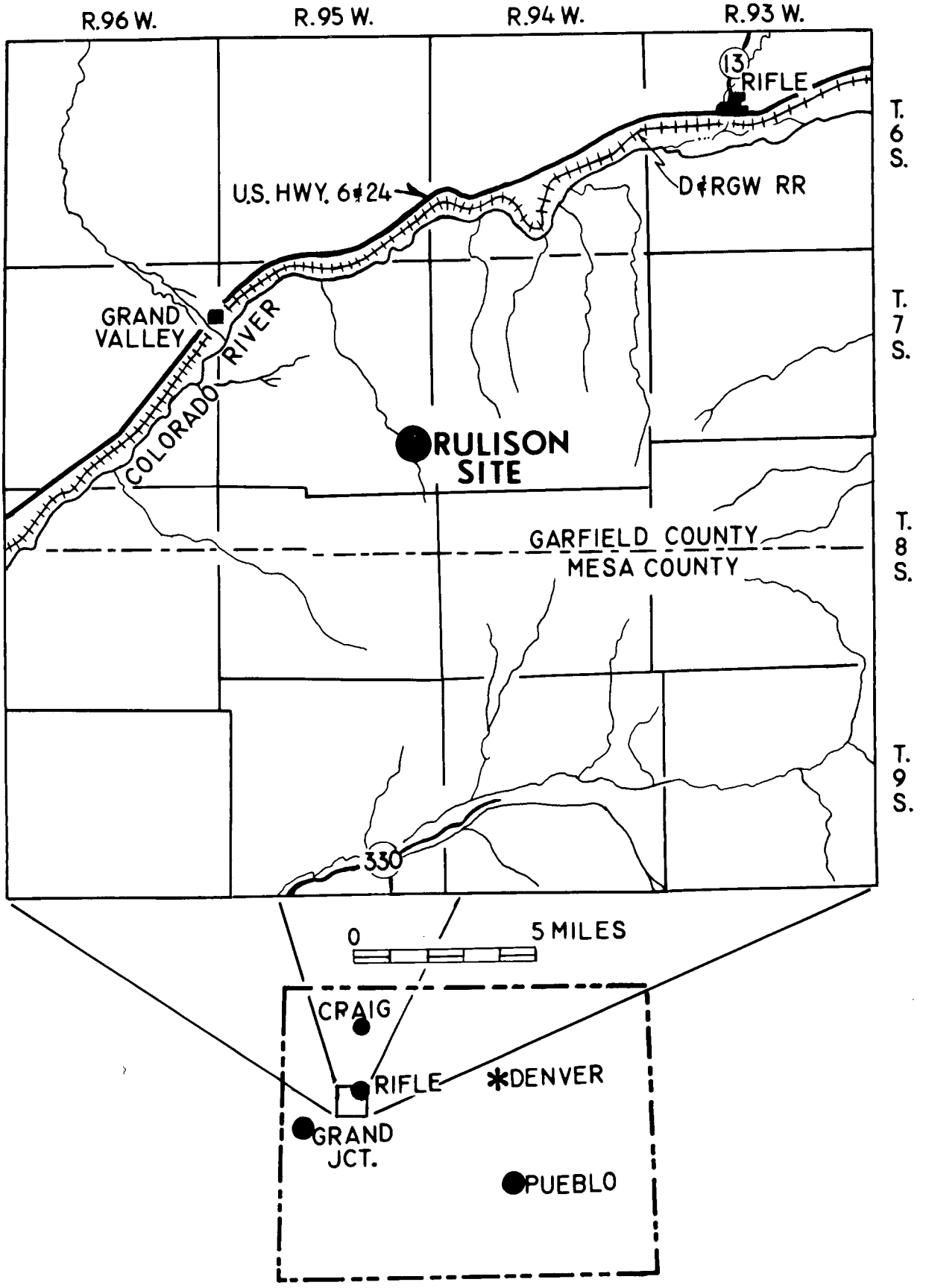


FIGURE 1.—Site of the Rulison Experiment, Garfield County, Colorado.

GEOLOGIC SETTING

The Project Rulison site is on the southwest limb of the Piceance Creek basin, a large northwest-trending structural downwarp in northwestern Colorado. Beds penetrated by the hole dip northeastward at 2° or less.

The northern part of the Piceance Creek basin drains to the White River; the southern part of the basin drains to the Colorado River. The Rulison site drains northward to the Colorado River.

The rocks underlying the Rulison site range in age from Quaternary to Precambrian. Marine and non-marine sedimentary rocks approximately 18,000 feet thick underlie the site. Formations below the Mesaverde Group of Late Cretaceous age, the deepest formations penetrated by the exploratory hole, are not described in this report.

The drilling of the exploratory hole (R-EX) at the Rulison site penetrated the following formations, in descending order: alluvium, Green River and Wasatch Formations of Eocene age, an unnamed unit of Paleocene age (probably correlative with the Fort Union Formation of the northern Rocky Mountain region, as described by Donnell, 1961, p. 844), Ohio Creek Conglomerate of Paleocene(?) age, and Mesaverde Group of Late Cretaceous age. The Mesaverde Group is of special interest, because the nuclear device will be detonated within this group. The resulting block-caving or collapse activity will form a chimney. Descriptions of the formations in the area of the test site follow.

Quaternary Deposits

Quaternary deposits composed of fine-grained to boulder-size material overlie the Green River Formation at the Rulison site. The deposits occur in the form of mudflows, talus accumulations, fan gravel, slump blocks, and the alluvium of Battlement Creek. Ground water occurs in the more permeable zones of these deposits.

Green River Formation

In and near the Rulison site the Green River Formation overlies the Wasatch Formation and contains four members. In ascending order, the members are Douglas Creek, Garden Gulch, Parachute Creek, and Evacuation Creek. At the R-EX well site, about 1,700 feet of the Green River Formation rests on the Wasatch Formation. The Green River Formation is composed chiefly of shale and marlstone. Sandstone, siltstone, and limestone occur in parts of the formation. Sandy zones in the lower part of the formation may be capable of yielding minor quantities of ground water.

Wasatch Formation

The Wasatch Formation overlies the unnamed unit of Paleocene age and consists principally of brightly-colored clay and shale. Sandstone lenses are a common feature. Locally, minor amounts of conglomerate, pebbly sandstone, limestone, coal, and black carbonaceous shale occur in the formation. The Wasatch Formation is approximately 3,900 feet thick at the Rulison site. The thickness of the formation will be greater than 3,900 feet if a thickness of less than 500 feet is selected for the underlying unnamed unit of Paleocene age. The Wasatch Formation is not a source of ground water in the Rulison gas field.

Unnamed Unit of Paleocene Age

The unnamed unit overlying the Ohio Creek Conglomerate consists of sandstone, shale, and a few thin coal beds. The thickness of the unit is probably less than 500 feet. The upper boundary has not been fixed, because the upper part grades into the overlying Wasatch Formation. The unit is not known to yield water in the Rulison gas field.

Ohio Creek Conglomerate

The Ohio Creek Conglomerate, which separates the underlying Mesaverde Group from the overlying unnamed unit of Paleocene age, is approximately 37 feet thick in hole R-EX. Thicknesses of as much as 76 feet have been penetrated in drill holes in other parts of the Rulison gas field. The Ohio Creek Conglomerate consists primarily of conglomerate, sandstone, and siltstone. In some of the gas wells in the Rulison gas field, the Ohio Creek Conglomerate has produced sufficient water to prevent air drilling of the formation; in other wells there was no water entry and air drilling was possible.

Mesaverde Group

The Mesaverde Group under the test site consists chiefly of sandstone and interbedded shale approximately 2,500 feet thick. The sediments were deposited in a near-shore environment that included marine, flood-plain, and coastal swamp conditions, which resulted in lateral and vertical differences in lithology. The sandstone layers are lenticular and many of them are on the order of a few thousand feet long. The Mesaverde Group does not yield substantial quantities of water.

HYDROLOGY

The principal surface hydrologic feature of the Rulison site is Battlement Creek, a tributary of the Colorado River (fig. 2). Battlement Creek carries most of the runoff to the river; some runoff is diverted for irrigation use; and some infiltrates the stream alluvium and terrace deposits. The underflow in the alluvium appears as springs in several places downstream from the Rulison site. A Geological Survey gaging station on Battlement Creek about 2½ miles downstream from the Rulison site was in operation from October 1956 to September 1965. The station's stream discharge record from October 1964 to September 1965 is shown on table 1.

The ground-water resources in the Rulison area are confined primarily to alluvium and terrace deposits. The underlying bedrock formations are generally impermeable and yield little or no water. A small amount of water was found in an upper Mesaverde sandstone lens during the drilling of hole R-EX. Later tests of this zone and other zones thought to contain water in the Mesaverde showed no measurable water production. Several deep drill holes in the Ohio Creek Conglomerate above the Mesaverde Group in the Rulison gas field have produced water; the remainder of the deep holes in this formation have produced no water. No water was produced from the Ohio Creek Conglomerate in hole R-EX. The Wasatch Formation contains some sandy zones in the middle and the upper parts of the formation; however, these zones produced no water in hole R-EX. The lower Green River Formation about 5,000 feet above the intended depth of emplacement of the nuclear device, has some sandy zones that produced water in sufficient quantities to make air drilling difficult.

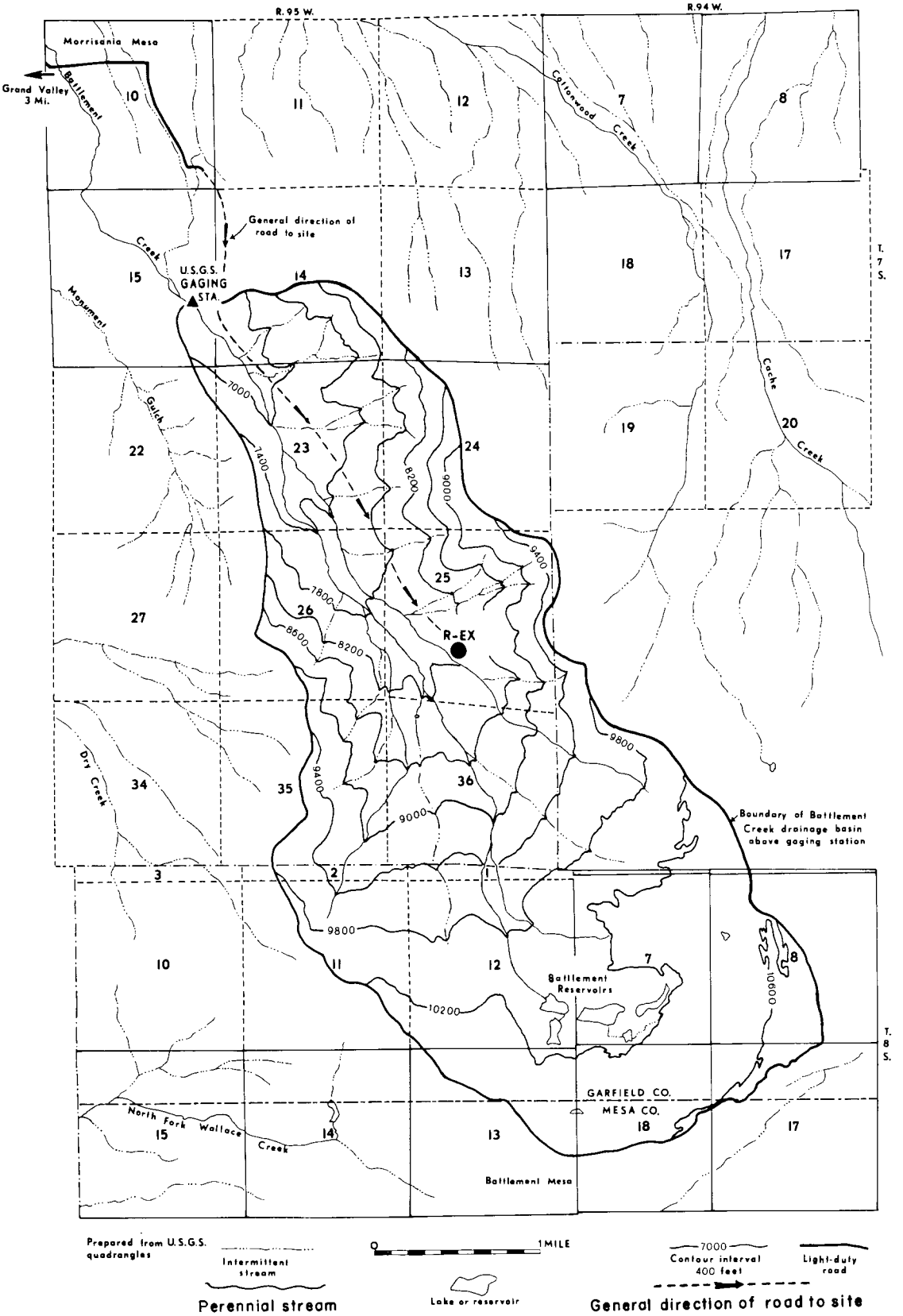


FIGURE 2.—Hydrologic and other features upstream from the former U.S. Geological Survey gaging station, Battlement Creek.

Table 1.--Discharge record of Battlement Creek from October 1964 to September 1965.

BATTLEMENT CREEK BASIN

9-926. *Battlement Creek near Grand Valley, Colo.*

Location.--Lat 39°26'10", long 107°58'40", in NE¼SE¼ sec.15, T.7 S., R.95 W., on left bank 300 ft downstream from ford, 4½ miles upstream from mouth, and 5 miles southeast of Grand Valley.

Drainage area.--10.5 sq mi.

Records available.--October 1956 to September 1965 (discontinued).

Gage.--Water-stage recorder and concrete control. Altitude of gage is 6,630 ft (from topographic map).

Average discharge.--9 years, 8.34 cfs (6,040 acre-ft per year). 1/

Extremes.--Maximum discharge during year, 63 cfs June 16 (gage height, 2.54 ft); minimum daily, 1.2 cfs Feb. 12-14.
1956-65: Maximum discharge, 102 cfs June 7, 1957 (gage height, 2.79 ft); maximum gage height, 2.96 ft May 26, 1958 (backwater from debris); minimum discharge not determined.

Remarks.--Records good except those for periods of ice effect or no gage-height record, which are poor. Slight regulation by Battlement Reservoir. No diversion above station.

Rating table, except periods of ice effect (gage height, in feet, and discharge, in cubic feet per second)

1.4	1.0	2.1	15
1.6	3.1	2.2	19
1.8	5.7	2.4	37
1.9	8.2	2.6	68

Discharge, in cubic feet per second, water year October 1964 to September 1965

Day	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
1	1.8	2.4	2.4	2.4	1.6	1.4	2.8	10	25	30	11	6.4
2	1.9	* 2.6	2.4	2.4	1.6	1.4	2.7	13	25	28	* 12	6.2
3	2.0	2.4	2.3	2.4	1.6	1.4	2.1	*13	25	25	12	6.4
4	2.1	2.2	2.3	2.3	1.6	1.4	1.9	13	28	25	11	6.2
5	2.3	2.2	2.2	2.2	*1.6	*1.6	*1.6	12	29	25	11	7.2
6	2.3	2.2	2.2	2.2	1.6	1.6	1.6	11	33	24	9.8	7.4
7	2.6	2.2	2.2	2.2	1.6	1.6	1.7	9.8	* 43	23	9.2	6.7
8	2.8	2.2	2.2	2.1	1.5	1.6	1.7	9.8	48	22	8.9	6.7
9	2.9	2.2	2.4	2.1	1.5	1.6	1.8	8.5	48	21	8.5	6.4
10	3.1	2.3	2.4	2.1	1.4	1.6	1.7	8.0	48	21	8.5	6.2
11	3.3	2.1	2.3	2.1	1.4	1.6	1.6	8.2	47	22	8.5	5.7
12	* 3.3	2.2	2.3	2.0	1.2	1.6	1.6	10	51	* 21	8.2	5.7
13	3.3	2.4	2.2	2.0	1.2	1.6	1.6	13	51	21	8.0	5.6
14	3.3	2.4	2.2	2.0	1.2	1.6	1.4	14	56	19	8.0	5.4
15	3.2	2.4	2.2	2.0	1.4	1.6	1.6	13	58	19	7.7	5.2
16	3.0	2.4	2.4	1.9	1.4	1.6	2.0	15	61	18	7.7	5.2
17	3.0	2.4	2.2	1.9	1.4	*1.6	2.3	* 20	60	17	8.0	5.7
18	2.9	2.4	2.0	1.9	1.4	1.6	2.2	27	58	17	8.9	7.0
19	2.9	2.6	2.2	1.9	1.4	1.4	*3.1	29	60	17	8.2	6.7
20	2.9	2.6	2.2	1.9	1.4	1.4	4.4	27	58	17	7.7	6.2
21	2.9	2.7	2.2	1.8	1.4	1.6	4.8	30	58	17	7.2	5.7
22	2.9	2.6	2.1	1.8	1.4	1.6	4.6	33	* 58	16	7.2	6.0
23	2.9	2.6	2.7	1.6	1.3	1.7	4.6	30	58	15	7.0	5.7
24	2.9	2.4	3.0	1.6	1.3	1.6	4.5	26	58	15	6.7	6.0
25	2.8	2.6	2.4	1.6	1.3	1.4	4.4	23	58	15	6.7	6.0
26	2.8	2.6	2.1	1.6	1.3	1.6	4.2	19	54	14	6.4	6.0
27	2.8	2.6	2.2	1.4	1.3	1.7	3.9	18	47	13	6.4	6.2
28	2.4	2.4	1.8	1.6	1.4	1.7	3.6	18	40	12	6.2	6.7
29	2.3	2.4	1.6	1.6		1.8	4.1	18	34	11	6.4	7.0
30	2.4	* 2.4	1.8	1.6	----------	2.0	6.7	19	32	11	* 6.7	6.4
31	2.4	----------	2.6	1.8	----------	2.3	----------	22	----------	12	6.4	----------
Total	84.4	72.1	69.7	60.0	39.7	49.8	86.8	540.3	1409	583	256.1	185.9
Mean	2.72	2.40	2.25	1.94	1.42	1.61	2.89	17.4	47.0	18.8	8.26	6.20
Ac-ft	167	143	138	119	79	99	172	1,070	2,790	1,160	508	369

Calendar year 1964: Max 63 Min - Mean 8.26 Ac-ft 6,000
Water year 1964-65: Max 61 Min 1.2 Mean 9.42 Ac-ft 6,810

Peak discharge (base, 40 cfs).--June 16 (0600) 63 cfs (2.54 ft).

* Discharge measurement made on this day.

Note.--Stage-discharge relation affected by ice Nov. 4, 5, 12, 14-20, 27, Dec. 7-9, 14-20, 29-31, Jan. 1, 2, Feb. 10-17, Mar. 18-22, 24-26, Apr. 11-15. No gage-height record Jan. 21 to Feb. 5, Mar. 2-17 (stage-discharge relation affected by ice during part of periods).

1/ Cubic foot per second (cfs) is the rate of discharge of a stream whose channel is 1 square foot in cross-sectional area and whose average velocity is 1 foot per second.

Table from: Water Resources Data for Colorado, Part 1, Surface Water Records, 1965. Prepared by Colorado District office, Water Resources Division, U.S. Geological Survey.

Ranchers on Morrisania Mesa obtain their domestic and livestock water from shallow wells in alluvium and terrace deposits or from cisterns and ponds which obtain their water from Battlement Creek and other small streams and springs.

Hydrologic Tests

All zones in hole R-EX below the unnamed unit of Paleocene age that yielded any water during drilling, or zones interpreted from geophysical logs as likely to contain water were evaluated by drill-stem testing techniques. The general procedure followed in testing was:

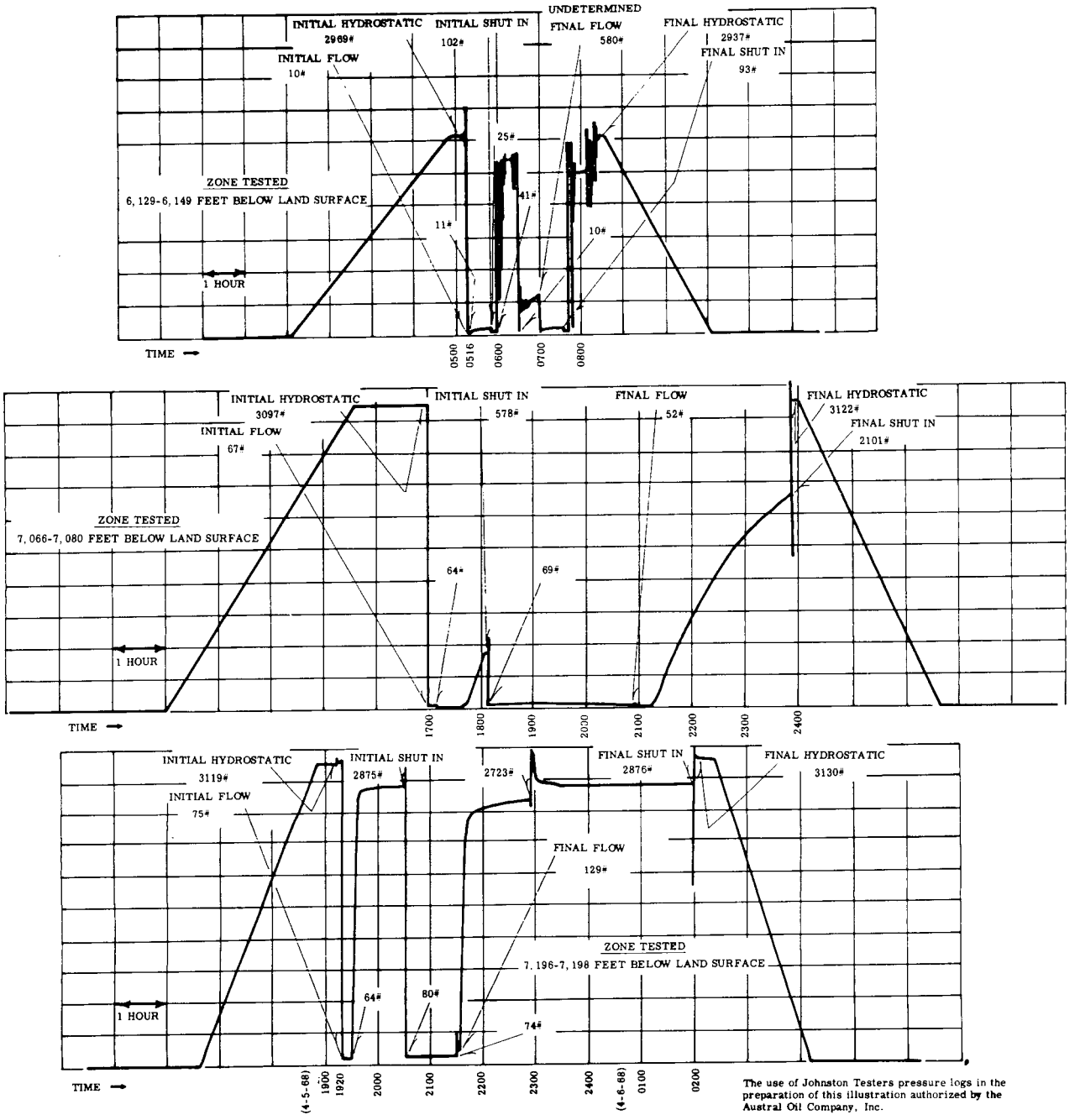
1. Perforate casing.
2. Install test tool.
3. Swab test when tool was open.
4. After swab test, remove test tool.
5. Cement off perforations.

Pressures recorded during the testing of the different zones indicate negligible or no fluid entry while the test tool was open. No fluid was recovered on any of the swab tests. Results of the tests are summarized in table 2. Graphs of the pressures from the tests are shown on figures 3 and 4. Samples of the fluid from the tubing immediately above the test tool were collected after the test tool was removed from the hole; the fluid probably entered the tubing after the packer was released. Spectrographic, radiochemical, and chemical analyses of the fluid recovered from the hole as well as the water (from tributary of Battlement Creek) used in hole construction, may

Table 2.--Summary of hydrologic tests, hole R-EX.

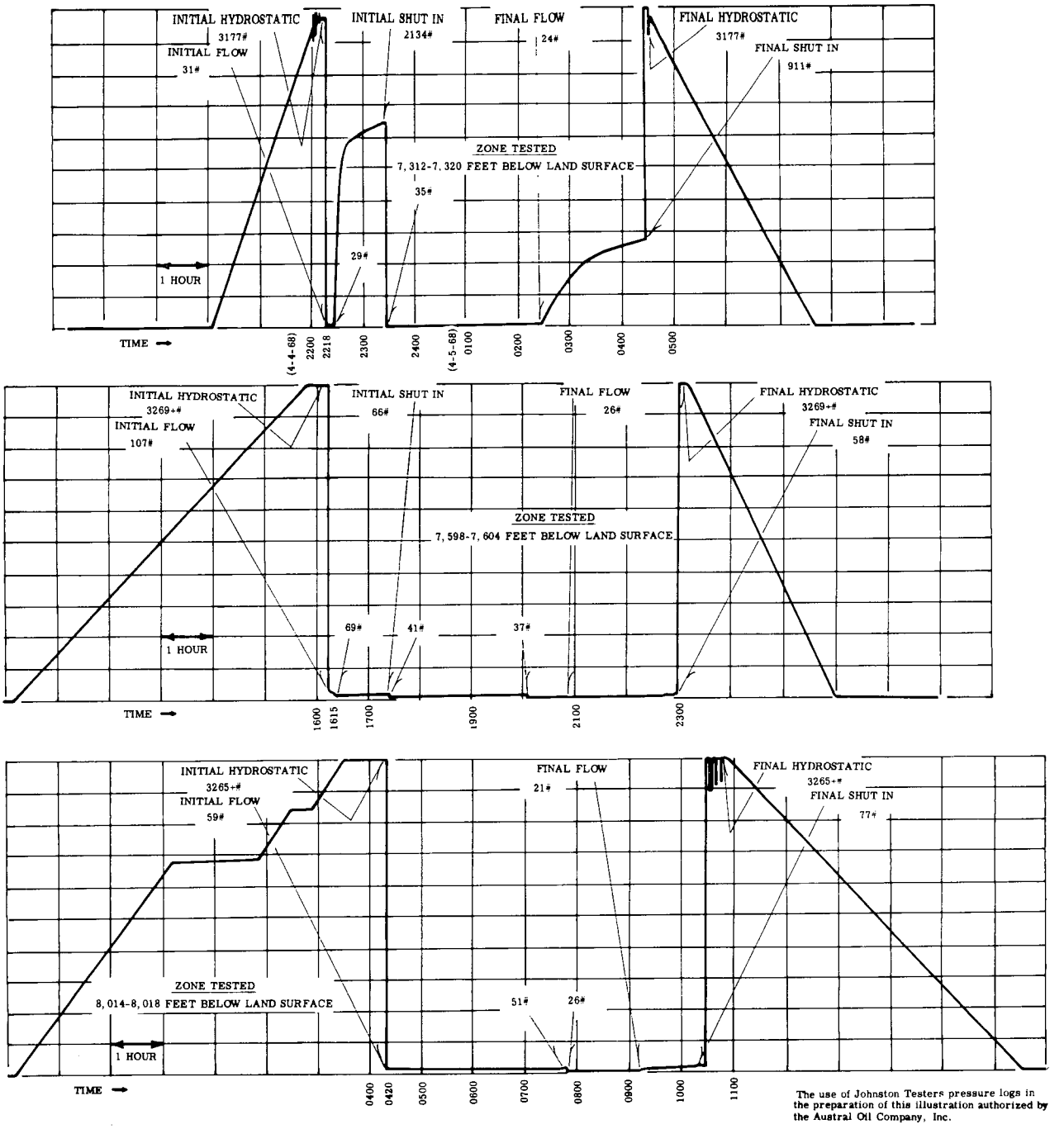
Geologic formation	Depth of zone tested below land surface (ft)	Date tested	Casing size (in)	Perforations	Type of test tool	Fluid entry during time tool was open	Bottom hole temp (^{o}F)	Remarks
Ohio Creek Conglomerate	6,129-6,149	1-15-68	7 5/8	3/8 in to 1/2 in 4 per ft	M.F.E.[1]	Pressure charts indicated no fluid entry.	151	Recovered about 15 gallons of drilling mud from top of test tool.
Mesaverde Group	7,066-7,080	4-8-68	5 1/2	3/8 in to 1/2 in 2 per ft	F.A.S.T.[2]	do	196	Swabbed to 7,004 ft below land surface. No fluid recovered. Recovered about 10 gallons of fluid from top of test tool.[3]
Do	7,196-7,198	4-5&6-68	do	do	do	do	195	Swabbed to 7,134 ft below land surface. No fluid recovered. Recovered about 240 gallons of fluid from top of test tool.[3]
Do	7,312-7,320	4-4&5-68	do	do	do	do	196	Swabbed to 7,250 ft below land surface. No fluid recovered. Recovered about 15 gallons of fluid from top of test tool.[3]
Do	7,598-7,604	4-3&4-68	do	do	do	do	197	Swabbed to 7,544 ft below land surface. No fluid recovered. Recovered about 20 gallons of fluid from top of test tool.[3]
Do	8,014-8,018	3-28-68	do	do	do	do	199	Swabbed to 7,929 ft below land surface. No fluid recovered. Recovered about 30 gallons of fluid from top of test tool.[3]

[1] Johnston Testers Multi-Flow Evaluator.
[2] Johnston Testers Fracturing Acidizing Squeezing Tool.
[3] Fluid likely to have entered the tubing after the packer was pulled loose. Represents drilling water rather than formation fluid.



The use of Johnston Testers pressure logs in the preparation of this illustration authorized by the Austral Oil Company, Inc.

FIGURE 3.—Graphs of pressures obtained during the drill-stem tests of zones 6,129-6,149; 7,066-7,080; and 7,196-7,198 feet, R-EX.



The use of Johnston Testers pressure logs in the preparation of this illustration authorized by the Austral Oil Company, Inc.

FIGURE 4.— Graphs of pressures obtained during the drill-stem tests of zones 7,312–7,320, 7,598–7,604, and 8,014–8,018 feet, R-EX.

be found in tables 3 and 4. The chemical character of the fluid in conjunction with the small amount recovered indicates that the samples consist primarily of drilling fluid rather than formation water. This is borne out by the pH values between 11.7 and 12.1 and high calcium ion concentrations indicating at least partial contamination by the cementing operation. The complete absence of formation water cannot be ruled out as attested to by regular variations in other ions such as the carbonate, sulfate, chloride, and sodium. The tritium content of the fluid indicates that it was derived from or contaminated by a surface source rather than from formation water.

CONCLUSIONS

All zones in hole R-EX below the unnamed unit of Paleocene age that yielded any water during drilling or zones interpreted from geophysical logs as likely to contain water were tested. The pressures recorded during the drill-stem tests of the different zones indicated negligible or no fluid entry to the hole. No fluid was recovered on any of the swab tests performed during the drill-stem tests. The chemical character of the fluid collected from the tubing immediately above the test tool after each test indicated that the fluid consisted primarily of drilling fluid rather than formation water, suggesting that little mobile water occurs in the zones tested.

Table 3.--Spectrographic and radiochemical analyses of fluids recovered from tubing above test tool after drill-stem tests, and of surface water used in hole construction, R-EX.

(Analyses by U.S. Geological Survey. Date below sample number is date of collection. Unless otherwise noted, data are in micrograms per liter.)

Spectrographic analyses

Element	(1) 3-28-68	(2) 4-4-68	(3) 4-5-68	(4) 4-6-68	(5) 4-9-68	(6) 12-24-67
Aluminum (Al)	--	--	--	--	--	65
Barium (Ba)	720	590	390	640	210	50
Beryllium (Be)	<.4	<.3	<.4	<.4	<.2	<.2
Bismuth (Bi)	<18	<14	<17	<20	<8	<3
Boron (B)	--	--	--	--	--	70
Cadmium (Cd)	<90	<70	<85	<95	<40	<15
Chromium (Cr)	1	4	2	<1	5	1
Cobalt (Co)	<2	<2	<2	<2	<2	<2
Copper (Cu)	90	850	1,100	75	7	1
Gallium (Ga)	<10	<7	<10	<10	<4	<2
Germanium (Ge)	<12	<10	<12	<13	<5	<2
Iron (Fe)	3	170	550	10	300	90
Lanthanum (La)	<2	<2	<2	<2	<2	--
Lead (Pb)	≟/11,000	≟/22,000	≟/35,000	≟/40,000	50	<2
Molybdenum (Mo)	70	110	120	60	23	2
Nickel (Ni)	10	6	13	3	2	<2
Silver (Ag)	17	2	.7	.9	11	<.2
Strontium (Sr)	--	--	--	--	--	200
Tin (Sn)	<20	<15	<20	<20	<8	<3
Titanium (Ti)	.6	1	5	.4	2	2
Vanadium (V)	1	<1	<1	<1	3	3
Ytterbium (Yb)	<.1	<.1	<.1	<.1	<.1	--
Yttrium (Y)	<.1	<.1	<.1	<.1	<.1	--
Zinc (Zn)	--	--	--	--	--	<10
Zirconium (Zr)	<2	<2	<2	<2	<2	ND

Radiochemical analyses

Uranium-Extractable	<.1	<.1	<.1	<.1	<.4	--
Gross beta (as Sr^{90}-Y^{90}, pc/l)	70	57	62	57	28	--
Gross alpha (as U equivalent)	<.4	9.8	<.4	6.4	<.4	--
Tritium, tritium units	<170	620	410	240	460	<350

-- Not determined.
< Less than figure shown.
≟/ By atomic absorption.
ND Specifically sought, not detected.

1. Zone tested, 8,014-8,018 feet below land surface, in Mesaverde Group.
2. Zone tested, 7,598-7,604 feet below land surface, in Mesaverde Group.
3. Zone tested, 7,312-7,320 feet below land surface, in Mesaverde Group.
4. Zone tested, 7,196-7,198 feet below land surface, in Mesaverde Group.
5. Zone tested, 7,066-7,080 feet below land surface, in Mesaverde Group.
6. Stream (tributary to Battlement Creek), SW¼NE¼SW¼ sec.25, T. 7 S., R. 95 W.,Garfield County, Colo.). Source of water for well construction.

Table 4.--Analyses of fluids recovered from tubing above test tool after drill-stem tests, and of surface water used in hole construction, R-EX.

(Analyses by U.S. Geological Survey. Date below sample number is date of collection. Unless otherwise noted, data are in milligrams per liter.)

	(1) 3-28-68	(2) 4-4-68	(3) 4-5-68	(4) 4-6-68	(5) 4-9-68	(6) 12-24-68
Silica (SiO_2)	8.0	2.6	0.4	2.0	5.2	25
Aluminum (Al)	2.9	1.8	1.8	1.5	.7	<.1
Iron (Fe)	.05	.14	.10	.02	.17	.02
Manganese (Mn)	<.01	.01	.01	.01	<.01	<.01
Strontium (Sr)	3.9	3.0	3.9	2.9	.93	.22
Calcium (Ca)	237	254	316	375	172	33
Magnesium (Mg)	<.1	<.1	<.1	<.1	.1	6.4
Sodium (Na)	223	109	114	125	29	14
Potassium (K)	80	67	79	70	17	1.0
Lithium (Li)	.20	.19	.23	.21	.03	<.01
Carbonate (CO_3)	181	164	132	108	32	0
Chloride (Cl)	54	40	20	20	6.0	.8
Copper (Cu)	.11	1.4	1.0	.16	.02	.01
Fluoride (F)	1.4	3.2	3.7	2.3	1.1	.3
Hydroxide (OH)	180	141	245	334	125	--
Nitrate (NO_3)	1.8	1.3	1.1	.6	1.7	.0
Phosphate (PO_4)	.0	.0	.0	.0	.0	.00
Selenium (Se)	.06	.05	.08	.07	.01	--
Sulfate (SO_4)	196	116	112	118	41	8.0
Zinc (Zn)	.57	1.2	1.9	1.4	.12	<.01
Boron (B)	.72	.53	.48	.39	.08	.05
Dissolved solids						
Res. on evap. at 180°C	1,550	1,220	1,340	1,400	498	157
Calculated	1,170	901	1,030	1,160	431	167
Hardness as $CaCO_3$						
Total	597	638	794	940	431	109
Non-carbonate	0	0	0	0	10	0
Specific conductance (μmhos/cm at 25°C)	3,880	2,900	4,080	4,950	1,940	263
pH	11.9	11.8	12.0	12.1	11.7	7.5
Percent sodium	41	25	22	21	12	22
Sodium-adsorption ratio (SAR)	4.0	1.9	1.8	1.8	.6	.6

< Less than figure shown. -- Not determined.

1. Zone tested, 8,014-8,018 feet below land surface, in Mesaverde Group.
2. Zone tested, 7,598-7,604 feet below land surface, in Mesaverde Group.
3. Zone tested, 7,312-7,320 feet below land surface, in Mesaverde Group.
4. Zone tested, 7,196-7,198 feet below land surface, in Mesaverde Group.
5. Zone tested, 7,066-7,080 feet below land surface, in Mesaverde Group.
6. Stream (tributary to Battlement Creek; SW¼NE¼SW¼ sec. 25, T. 7 S., R. 95 W., Garfield Co., Colo.). Source of water for well construction.

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